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Plio-Pleistocene floras of the Vildštejn Formation in the Cheb Basin, Czech Republic – a floristic and palaeoenvironmental review

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Abstract

Fossil plant assemblages (foliage, fruits and seeds, pollen, wood) from the Pliocene and early Pleistocene deposits in W Bohemia (the Vildštejn Formation of the Cheb Basin, Tachov /Cheb–Domažlice/ Graben) are newly analysed using several palaeoenvironmental methods aiming at reconstructing palaeovegetation and palaeoclimatic changes. Floras of four subsequent stratigraphic levels show a decreasing representation of exotic elements in the Pliocene and a massive immigration of boreal elements in the Early Pleistocene. Vegetation changes start with broad-leaved deciduous and mixed mesophytic forests (BLDF, MMF) and continue to “more open” light forests of BLDF or MMF types in areas of zonal to extrazonal uplands. This vegetational change is characterised by an immigration of dry herbaceous and sclerophyllous elements. Wetland communities stepwise lose exotic components and point to cool-temperate conditions similar to the present higher in the profiles. Palaeoclimatic signals show warmer and more humid conditions for the Pliocene levels (about 15°C of mean annual temperature, 5°C of mean winter and 25°C of mean summer temperature, more than 900 mm of mean annual precipitation). Early Pleistocene proxy data indicate the beginning of a cooler phase at the Plio-Pleistocene boundary (about 7°C of mean annual temperature and decreasing trend of precipitation), but no colder conditions than the present day in the NW part of the Bohemian Massif.

Key words: flora; vegetation; palaeoclimate; Pliocene; Pleistocene; Czech Republic

1. Introduction

41 Plant assemblages (foliage, fruits and seeds, pollen, wood) obtained from drill cores and
42 outcrops of the Vildštejn Formation in the Cheb Basin and the Tachov (Cheb–Domažlice)
43 Graben in western Bohemia were assigned by Bůžek et al. (1985) to the Pliocene-Pleistocene
44 transition, according to the stratigraphic scheme of Gibbard et al. (2010). The fossils have
45 been known since pioneer studies by Karl Rudolph in 1935 and were more systematically
46 evaluated by Č. Bůžek, Z. Kvaček, F. Holý, M. Konzalová, and L. Stuchlik from 1982 to 1991
47 (Rudolph, 1935; Bůžek et al., 1982, 1985; Stuchlik, 1982, unpublished). In the present paper
48 the plant material described so far (Bůžek et al., 1985; Stuchlik, 1982) is re-evaluated in
49 current taxonomical context (EM, ZK, VT) and results of subsequently analysed new pollen
50 material (Stuchlik, unpublished) are added (AAB, LS). Several palaeoenvironmental
51 techniques are applied on the complete fossil plant spectra from the Vildštejn Formation
52 (Cheb Basin) and relicts of Neogene deposits of the Tachov (Cheb–Domažlice) Graben to
53 reconstruct models of vegetation and climatic changes from the Late Pliocene to Early
54 Pleistocene. The evaluation of the zonal vegetation at the studied sites was conducted using
55 a semi-quantitative method of the Integrated Plant Record vegetation analysis (VT). This
56 technique was originally designed to reconstruct the character of zonal vegetation under
57 subtropical to temperate climate. Here for the first time, the IPR-vegetation analysis is
58 applied on Plio-Pleistocene floras originated partly under cool-temperate conditions. The
59 obtained results are discussed in the context of those derived from other palaeovegetational
60 techniques allowing to reconstruct complex qualitative and quantitative characteristics of
61 the fossil vegetation, i.e., Phytosociological approach (ZK, VT) and Plant Community Scenario
62 approach (EV, EM). Similarly, the multi-technique approach was used to detect climatic

changes during the sedimentation of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben. The method of the Coexistence Approach (AAB) assesses palaeoclimatic estimates based on the analysis of the micro- and macrofossil plant material. The second palaeoclimatic technique is the physiognomic method of the Leaf Margin Analysis (VT). Its application is strongly limited by the scarcity of the leaf material at the studied sites. Therefore we experimentally used also elements from carpological material and estimated characters of the leaf lamina (entire vs. non-entire) based on their nearest living relatives (NLRs). The obtained climatic datasets and CA results are discussed within the frame of palaeoclimatic data obtained for other Late Pliocene and Early Pleistocene floras of Europe.

2. Geological setting

The Cheb Basin, the westernmost lignite basin within the Ohře (Eger) Graben lies on a tectonic crossing of two major structures – the Ohře (Eger) Rift of WSW-ENE direction (Ziegler, 1990) and a younger structure of the Tachov (Cheb–Domažlice) Graben trending in NNW-SSE direction (e.g., Rojík et al., 2010; Fig. 1a). Its sedimentary filling consists of several lithostratigraphic units (formations or levels), partly informally defined, deposited in the time interval from Late Eocene to Pliocene-Pleistocene (e.g., Ambrož, 1958; Václ, 1979; Bůžek, et al. 1982; Bucha et al., 1990; Špičáková et al., 2000; Kvaček and Teodoridis, 2007; Rojík et al., 2010). Besides the formally defined formations of Staré Sedlo (Late Eocene), Cypris (late Early Miocene) and Vildštejn (Plio-Pleistocene), the other lithostratigraphic units, i.e., the Lower Clay and Sand with the Lower Coal Seam and the Main Coal Seam are

84 informally defined. Recently, Špičáková et al. (2000) described a detailed tectono-
85 sedimentary evaluation of the Cheb Basin and the Tachov (Cheb–Domažlice) Graben
86 focusing on three main depositional units only, i.e., the Lower Clay and Sand and Main Coal
87 units, Cypris Formation and Vildštejn Formation. Rojík et al. (2010) and Kvaček and
88 Teodoridis (2007) reviewed most of the so far published palaeobotanical data from the Cheb
89 Basin with details of the geological positions. The present account will concentrate only on
90 the youngest part of the basin fill, the Vildštejn Formation. This cycle of fluvio-lacustrine
91 sediments was deposited after a hiatus lasting for about 12 million years partly on the Early
92 Miocene Cypris Formation or on crystalline and granitic basement near the western border
93 of the basin. The average thickness of the Vildštejn Formation usually varies from 30 to 60
94 m, but the maximal value exceeds 100 m at the Mariánské Lázně fault belonging to the
95 tectonic system of the Tachov (Cheb–Domažlice) Graben. The Vildštejn Formation is divided
96 into two members. The older Vonšov Member is well developed near the villages of Skalná
97 (formerly Vildštejn or Wildstein) and Vonšov (formerly Fonsau) and represents weathered
98 illite green clay (partly reworked Cypris claystone), grey-violet or reddish tough clay (Blauton
99 D) and tough blue-grey pelite associated with kaolinite. Towards the East and North of the
100 basin, sandy deposits start to occur and intermix with pelitic deposits. The younger Nová Ves
101 Member represents a relatively heterogeneous sequence of layers with a total thickness of
102 20 to 50 m. The basal part is characterised by a thick layer of the dark to black clay (called
103 Nero), which is accompanied by lignitic peat horizons in its uppermost part (Nová Ves clay
104 pit) that form the overlying Upper Coal Seam (Václ, 1979), which typically include sandy and
105 mica laminations. According to Bůžek et al. (1985, p. 10), the Nero Clay, generally regarded

106 as a basal layer of the Nová Ves Member (Fig. 1), belongs rather to the sedimentary cycle of
107 the Vonšov Member because this clay deposit is coarser, rich in mica and contains only
108 kaolinite with less ordered structure and lower content of molecular water like clays of the
109 Vonšov Member. Pure ball clays are whitish (except the Nero Clay) and form layers mostly in
110 the lower part of the Nová Ves Member. The upper part is characterised by prevailing
111 psammitic sediments. According to Bůžek et al. (1985), the uppermost part of the Nová Ves
112 Member (Overlying sands and gravels sensu Ambrož, 1958; horizon D in this paper) surely
113 represents an independent sedimentary cycle (Fig. 1a, b).

114 The Tachov (Cheb–Domažlice) Graben is partly filled by Neogene deposits which have been
115 interpreted as fluvial sediments of “the river F” sensu Pešek and Spudil (1986). This river
116 system probably drained the western part of the Czech Republic towards the Cheb Basin
117 during the Pliocene (Pešek and Spudil, 1986; Malkovský, 1995). The studied plant macro- and
118 microfossils are known from the V1 and V2 drill cores and the Nová Hospoda clay pit (Fig.
119 1a). The geological section of the drill cores, as described by Nosek (1978), consists of about
120 10 m thick clayey sediments with thin lignitic beds and brown clays that interchange with
121 kaolinitic clays and claystones. This fossiliferous part (mainly clayey horizons) is overlain by 5
122 m thick reddish weathered deposits (Bůžek et al., 1985). Pollen material was obtained from
123 the Nová Hospoda clay pit (Gabrielová et al., 1970; Konzalová in Bůžek et al., 1985).

124 Exact dating of fossiliferous deposits of the Vildštejn Formation and the Tachov (Cheb–
125 Domažlice) Graben is not always available (Fig. 1b). The palaeomagnetic records derived
126 from the drill cores of NK-24 and NK-25 (Nový Kostel) suppose a time range from 4.7 to 1.4
127 Ma (Bucha et al., 1990), although these datasets must be taken just as rough estimates

(Špičáková et al., 2000, pp. 561-562; Matys-Grygar, pers. comm. 2013). Špičáková et al. (2000) present a time range from 4.5 to 1.5 Ma for the deposition of the Vildštejn Formation as a whole.

3. Material

Due to the scarcity of outcrops (mainly the Nová Ves, Vonšov and Nová Hospoda clay pits), the majority of plant material studied derives from drill cores generally situated in the NE part of the Cheb Basin (Fig. 1). The present study aims at re-evaluating all macrofossil as well as microfossil (palynological) material described by Bůžek et al. (1985). In addition, new pollen datasets from the drill core HV 2 and the Nová Ves clay pit (Fig. 2, Appendix 1) are provided. These data are the first quantitative pollen data published for this region and allow for a more detailed analysis of vegetation and climate changes.

The study follows the original concept of fossiliferous horizons within the Vildštejn Formation given by Bůžek et al. (1985) and recognizes four stratigraphic levels for quantitative analyses:

(1) Vonšov Member (Fig. 1; Table 1 – marked as B, or I.) – this level includes macrofossil floras from the drill core HV 9, and pollen data from the lower part of the Nová Ves clay pit (levels A1-A3) and the lower part of drill cores HV 2 and HV 3 (Stuchlik, 1982). Due to the sandy facies in drill cores HV 2 and HV 3 the stratigraphic boundaries between the Vonšov and Nová Ves members cannot be clearly fixed. They were characterised by Stuchlik (1982)

by comparing the palynological assemblages with data from the Nová Ves clay pit. The middle parts of drill cores HV 2 and HV 3 show abundant occurrences of *Alnus* and other riparian and wetland elements (*Salix*, *Nyssa*, Cyperaceae, etc.) as well as significant occurrences of *Betula*, *Corylus*, and *Myrica*, and are comparable with part “A” (Pluto Clay) of the Nová Ves clay pit (Stuchlik, 1982). The original pollen material collected by Stuchlik from the drill core HV 2 and the Nová Ves clay pit was re-studied by us (Appendix 1). Pollen datasets from drill core HV 3 were not available. Although a clear position of the boundary between the Pluto and Nero clays is not given by Stuchlik (1982) and correlation of the pollen diagrams remains vague, we assign pollen samples from the depths of 35.3 m to 55.2 m to the Pluto Clay in the drill core HV 2 (Bůžek et al., 1985, Fig. 2) based on the above mentioned similarities in the floristic composition of the levels.

(2) Nová Ves Member (Fig. 1; Table 1 – marked as C, or II.) – this second level comprises macrofloras from drill cores HV 3, HV 4 (29.1–34.4 m), HV 6, HV 7, V 51–V 67, and pollen data from drill cores HV 2 (25.6–19.5 m) and HV 3, and the Vonšov and Nová Ves clay pits (samples B1–B4). The uppermost parts of the drill cores HV 2 and HV 3 contain pollen samples showing higher abundances of Taxodioideae/Cupressaceae, *Corylus*, Leguminosae, *Myrica*, and Rhamnaceae, and are comparable to the “level I.” of the Nero Clay sensu Stuchlik (1982), i.e., the part “B” of the Nová Ves clay pit.

(3) Nová Ves Member – lignite beds (Fig. 1; Table 1 – marked as D, or III.) –this level includes macrofloras from the upper part of the drill core HV 4 (22.8–24.3m) and the Nová Ves clay pit (layers NV 9–10) as well as pollen samples from the Nová Ves clay pit (horizons B5–B9 and C1–C7).

(4) Nová Ves Member – upper part (Fig. 1; Table 1 – marked as E, or IV.) – the macroflora from layer NV 14 and pollen samples from horizons C9, C₁₋₄ and D in the Nová Ves clay pit are included here.

Separately, a composite flora of the **Tachov (Cheb–Domažlice) Graben** (Fig. 1a; Table 1 – marked as A) is evaluated in this study, which consists of macrofloras from drill cores V 1 and V 2, and pollen data from the outcrop at Nová Hospoda (Konzalová in Bůžek et al. 1985).

4. Floristic analysis and phytostратigraphic correlation

The individual palaeofloristic levels within the Vildštejn Formation significantly differ in the composition and rate of geoelements (Bůžek et al. 1982, 1985; Table 1; Fig. 2; Appendix 1). The lowermost parts represent the fill of the Tachov (Cheb–Domažlice) Graben, where, besides common remains of *Glyptostrobus*, also *Corylopsis*, *Symplocos casparyi* and *Microdiptera* (incl. *Mneme*) were recorded in the macrofossil assemblage (palaeofloral assemblage A) stressing affinities with the Early Pliocene (Zanclean, 5.3–3.6 Ma) floras of the Netherlands (Brunssumian – Reid and Reid, 1915; Zagwijn, 1959), the Lower Rhine Basin (Hambach 9 ‘Rot-Ton’ – Van der Burgh and Zetter, 1998; Wetterau – Mai, 1973), Alsace (Sessenheim ‘Saugbagger-Flora’ – Geissert et al., 1990; Kvaček et al., 2008; Teodoridis et al., 2009), Poland (Krościenko – Szafer, 1947, Mizerna II). In Italy *Symplocos casparyi* is reported up to the Gelasian (about 2 Ma – Martinetto, 2001; Martinetto et al., 2015), and *Glyptostrobus* certainly still occurs in deposits of late Piacenzian age (ca. 2.8 Ma – Martinetto et al., 2007), and there are possible Gelasian records in central Italy (Martinetto et al., 2014)

191 as well as a problematic wood record in the Calabrian (ca. 1.5 Ma – Ravazzi and Van der
 192 Burgh, 1994), whereas *Corylopsis* and *Microdiptera* have never been recorded there. If a
 193 correlation of the Cheb Basin to the Italian palaeofloral sequence was attempted, the
 194 assemblage A of Vildštejn would certainly admit a Piacenzian age (3.6–2.6 Ma), but a
 195 Gelasian age could not be excluded. The macrofloras of the Pluto and Nero clays (the Vonšov
 196 Member and the lower part of the Nová Ves Member) are richer, including besides
 197 *Glyptostrobus* also other exotic conifers (cf. *Taxodium*, *Chamaecyparis*, *Pinus* cf. *spinosa*,
 198 *Picea* cf. *echinata*) and angiosperms (*Liriodendron*, *Ampelopsis*, *Acer* cf. *tricuspidatum*,
 199 *Viburnum* cf. *dilatatum*, *Weigela*, *Leucothoë narbonnensis*, *Epipremnites*). The common
 200 occurrence of *Quercus roburoides* and *Quercus* cf. *pseudocastanea* stresses close affinities to
 201 the Late Pliocene (Reuverian, Piacenzian) floras of Europe, e.g., Frankfurt a. M. (Germany) –
 202 Mädlar (1939); Willershausen (Germany) – Straus (1992), Knobloch (1998); Berga (Germany)
 203 – Mai and Walther (1988); Auenheim (France) – Kvaček et al. (2008), Teodoridis et al. (2009);
 204 Ruszów (Poland) – Hummel (1983, 1991). Also the comparison to the Italian floras points to a
 205 Piacenzian age, because there *Taxodium*, *Weigela*, *Leucothoë* and *Epipremnites* are only
 206 reported up to the late Piacenzian (ca. 2.8 Ma – Martinetto, 1999; Martinetto et al., 2007).
 207 According to Bůžek et al. (1985) the rate of exotic elements in the Tachov (Cheb–Domažlice)
 208 Graben and Pluto and Nero clays is 30% and 33%, respectively, whereas a transition to the
 209 higher levels of the Vildštejn Formation is indicated by a turnover of floristic characteristics.
 210 The flora of the lignite beds of the Nová Ves Member differs pronouncedly by the new
 211 immigration of elements that appear commonly in the European Pleistocene, mainly *Picea*
 212 *omoricoides*, *Pinus* cf. *sylvestris*, boreal Ericaceae (*Chamaedaphne*, *Oxycoccus*, *Andromeda*),

and various herbs, which are typical of central to subarctic Eurasia today (*Scheuchzeria*, *Ranunculus flammula*, *Menyanthes* cf. *trifoliata*). The poorly documented higher levels of the mica clay from the upper part of the Nová Ves Member are dominated by the short-needle Scotch pine typical of boreal Scandinavia, with other Pinaceae, *Juniperus*, dwarf *Salix* and *Alnus*. The rate of exotic elements within the Nová Ves Member decreases to hardly 22% of the total number of taxa.

5. Methods

Five palaeoenvironmental methods have been applied in this study: Phytosociological approach, Integrated Plant Record vegetation analysis (IPR-vegetation analysis), Plant Community Scenario approach (PCS approach), Coexistence Approach (CA) and Leaf Margin Analysis (LMA). The confrontation of these methods allows in our opinion a more precise evaluation of palaeoenvironmental and palaeoclimatic aspects based on the plant fossil material studied. The method proposed by Bertini and Martinetto (2011) for the construction of palaeovegetation transects, which would have been useful to test the qualitative transects proposed for the Vildštejn palaeofloras by Bůžek et al. (1985), could not be applied because it requires several localities of the same age in different palaeogeographic contexts.

5.1 Phytosociological approach

The phytosociological approach is a widespread and the earliest vegetation reconstruction method, which is known as an intuitive qualitative approach (e.g., Heer, 1855; Saporta and Marion, 1878; Saporta, 1881; for review see Mai, 1995). Several palaeophytocenological markers are usually selected based on their abundance, and their physiognomical and taxonomical characters. On this basis the defined palaeovegetation units (including their nearest living relatives (NLRs) environmental datasets) are correlated to suitable extant vegetation units and/or subunits. Mai (1995, p. 498–603) presents most of the published vegetation types and their synonyms, thus providing a detailed overview of zonal and azonal phytosociological units in current use for the Paleogene and Neogene of Europe (Teodoridis et al. 2011a, pp. 161–162).

5.2 Integrated Plant Record vegetation analysis (IPR-vegetation analysis)

The IPR-vegetation analysis is a semi-quantitative evaluation technique developed by Kovar-Eder and Kvaček (2003) to map the integrated plant fossil records (leaf, carpological, wood, and pollen assemblages) in terms of the zonal vegetation (Kovar-Eder and Kvaček, 2007; Kovar-Eder et al., 2008). Methodologically, the IPR-vegetation analysis uses plant taxonomy, physiognomy, and autoecological characteristics to assign the studied plant record into twelve zonal (9) and azonal (3) taxonomic-physiognomic components: CONIFER (zonal and extrazonal conifers), BLD (broad-leaved deciduous woody angiosperms), BLE (broad-leaved evergreen woody angiosperms), SCL (sclerophyllous woody angiosperms), LEG (legume-like woody angiosperms), ZONPALM (zonal palms), ARBFERN (zonal arborescent ferns), DRY

254 HERB (open woodland and grassland elements), MESO HERB (mesophytic forest
 255 undergrowth), AZONAL WOODY (azonal woody trees and shrubs), AZNW (azonal non-woody
 256 elements) and AQUATIC (aquatic elements). A last component of PROBLEMATIC taxa
 257 includes unassigned taxa. The relative abundances of the various components of zonal
 258 woody angiosperms and zonal herb component (MESO HERB + DRY HERB) of zonal woody
 259 components are calculated as follows in Eqs 1 to 5.

260 Eq. 1: $\%_{BLD} = BLD / (\sum(BLD, BLE, SCL, LEG, ZONPALM)) \times 100,$

261 Eq. 2: $\%_{BLE} = BLE / (\sum(BLD, BLE, SCL, LEG, ZONPALM)) \times 100,$

262 Eq. 3: $\%_{SCL+LEG} = SCL+LEG / (\sum(BLD, BLE, SCL, LEG, ZONPALM)) \times 100,$

263 Eq. 4: $\%_{CONIFER} = CONIFER / (\sum(BLD, BLE, SCL, LEG, ZONPALM, CONIFER, MESO HERB, DRY HERB))$
 264 $\times 100.$

265 Eq. 5: $\%_{\text{DRY HERB} + \text{MESO HERB}} = \text{DRY HERB} + \text{MESO HERB}$
 266 $/ (\sum(BLD, BLE, SCL, LEG, ZONPALM, CONIFER, MESO HERB, DRY HERB)) \times 100.$

267 These values (Eqs 1 to 5) have been defined as distinguishing 8 zonal vegetation types
 268 including their ecotones (Kovar-Eder and Kvaček, 2007; Teodoridis et al., 2011a): 1)
 269 temperate to warm-temperate broad-leaved deciduous forests (BLDF); 2) warm-temperate
 270 to subtropical mixed mesophytic forests (MMF); 3) subtropical broad-leaved evergreen
 271 forests (BLEF); 4) subtropical, subhumid sclerophyllous or microphyllous forests (ShSF); 5)
 272 ecotone vegetation of BLDF/MMF; 6) ecotone vegetation of BLEF/MMF; 7) xeric open
 273 woodlands (OW); and 8) xeric grasslands or steppe (= Xeric grassland). Thresholds for

vegetation types 1 to 4 were validated on living assemblages from China and Japan considering also the definition of the transitional vegetation (Teodoridis et al., 2011b). A new IPR-vegetation database was built to organise and summarise the existing fossil and modern results (Teodoridis et al., 2011a; for details see www.iprdatabase.eu). Recently, Teodoridis et al. (2012) also tested the IPR vegetation analysis on Palaeogene European floras and modern tropical vegetation from China.

Due to the low diversity especially of zonal woody angiosperms in the studied material from the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the IPR vegetation analysis is not reliably applicable to many of the assemblages (for less than 12 zonal woody angiosperm taxa – see Table 2). However, the values of coniferous and herbaceous components (CONIFER, DRY HERB, MESO HERB) are still informative in these cases, because they are calculated based on the sum of all zonal taxa (see Eqs 4, 5).

5.3 Plant Community Scenario approach (PCS approach)

Leaf, carpological and pollen datasets of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben are re-evaluated also by means of a recently proposed standardised approach for quantitative plant assemblage analysis and graphical rendering of floral-palaeofloral data: the “Plant Community Scenario” (PCS) approach (Martinetto and Vassio, 2010; Vassio and Martinetto, 2012). The PCS approach is based on the standardised quantitative analysis of plant assemblages in a given volume of sediment. The quantitative data concerning a single category of plant parts (e.g. carpological remains, leaves, pollen and

spores) and some related qualitative attributes are then converted and illustrated in a simplified 2D sketch (PCS) which has a similar appearance as a vegetation transect. Qualitative information provided for each taxon is synthesised into the PCS by means of “growth forms” (plant categories, Appendix 2) and by subdividing the profile of the PCS transect into different ecological subzones (dry, mesophytic, hygrophilous, aquatic) to better display the ecological preferences of the dominant taxa. The resulting vegetation transect conventionally comprises 50 “plant symbols” proportional to the relative abundance of each plant category in the studied assemblage. The analysis of plant assemblages by means of the PCS approach and the visualisation of vegetation sketches allow the standardised, homogeneous and easy comparison within palaeobotanical datasets (Figs 3, 4 and 5). The PCS approach, so far restricted mainly to carpological assemblages (Martinetto and Vassio, 2010; Vassio, 2012; Vassio and Martinetto, 2012), can also be applied to pollen (Martinetto et al., 2012; Vassio, 2012) and leaf assemblages (Vassio, 2012). Yet, initial results in using the PCS representation for palaeovegetation reconstruction have been obtained only for fruit and seed assemblages based on the combined study of modern standing vegetation (directly surveyed) in a limited catchment area and the modern carpological assemblages buried by its drainage system (Vassio, 2012; Vassio and Martinetto, 2012; Fig. 6). The aim of this research was to describe the quantitative taphonomical bias between the real standing vegetation and the final composition of the carpological assemblages originated from it. The gathered data were used to produce coupled vegetation survey-PCS and deposit-PCS, whose comparison is the key for a better interpretation of a deposit-PCS in a fossil context, in which the corresponding palaeovegetation represents the unknown variable (Vassio, 2012; Vassio

and Martinetto, 2012). The pictures of the vegetation provided by modern deposit–PCSs can be assumed as models to be compared with ancient deposit–PCS in order to find the best modern deposit analogues. Then, the coupled information of modern deposit–PCS plus modern vegetation-PCS can be used as a key for the interpretation of the PCSs obtained from fossil assemblages. At present, the number and the environmental coverage of modern deposit-PCSs is still not sufficient to always enable the determination of modern models of vegetation for fossil assemblages (Bertolotto et al., 2012; Vassio, 2012; Vassio and Martinetto, 2012).

In the present paper, the first experiment of applying the quantitative PCS approach to three plant part records (carpological remains, leaves, pollen and spores) collected from the same sedimentary layers aims at pointing out, discussing and comparing different information, i.e., the represented source area, a possible taphonomical bias, and peculiarities provided by each palaeobotanical dataset.

5.4 Coexistence Approach (CA)

The five flora lists of the different stratigraphic levels described above and given in Table 1 have been assigned to quantitative climatic analyses with the Coexistence Approach (CA, Mosbrugger and Utescher, 1997; Utescher et al., 2014) for micro- and macrofloras separately to compare local and regional climate signals. Due to the general agreements of both signals, micro and macro data also have been combined to provide a higher resolution of results. Additionally, the CA has been applied to all single pollen floras of the drill core HV

2 and Nová Ves clay pit separately (Appendix 1) to assess the climate variability within the studied stratigraphic interval of the Vildštejn Formation. Seven climate parameters have been calculated by the CA: MAT (mean annual temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual precipitation), as well as HMP (precipitation of the wettest month), LMP (precipitation of the driest month), and WMP (precipitation of the warmest month). Based on the assumption that the climatic requirements of Neogene plant taxa are similar to those of their nearest living relatives (NLRs), the aim of the CA is to find the climatic ranges in which a maximum number of NLRs of a given fossil flora can coexist. Those coexistence intervals (one for each climate parameter) are considered the best description of the palaeoclimatic situation under which the given fossil flora lived (for a detailed discussion and introduction to the method see Mosbrugger and Utescher, 1997 and Utescher et al., 2000, 2014). The application of the CA is facilitated by the computer program ClimStat and the database PALAEOFLORA which contains NLRs of more than 7500 Cenozoic plant taxa, together with their climatic requirements (1730 datasets) which are derived from meteorological stations located within the distribution areas of the taxa (for details see www.palaeoflora.de). The resolution of the calculated climate data varies with respect to the parameter examined; it is highest for temperature-related parameters where it is usually in the range of 1 to 2 °C; results for mean annual precipitation reach an accuracy of 100 to 200 mm (Mosbrugger and Utescher, 1997). Typically, the resolution and the reliability of the resulting coexistence intervals increase with the number of taxa included in the analysis, and are relatively high in floras with ten or more taxa for which climate parameters are known.

Some authors doubt the reliability of the Coexistence Approach especially for certain environmental conditions like mountainous regions (e.g., Kvaček, 2007; Grimm and Denk, 2012). However, methodological proxy-proxy and model-proxy comparisons as well as several applications of the CA on Oligocene to Pliocene European floras showed its reliability and good climatic resolution (e.g., Bruch et al., 2007, 2011; Utescher et al., 2011, 2014). Utescher et al. (2014) discuss these controversies and give a detailed overview of the power and limitations of the Coexistence Approach. To get additional independent climate data for comparison and validation, Leaf Margin Analysis (LMA) has been conducted to the material as well.

5.5 Leaf Margin Analysis (LMA)

Leaf margin analysis is a univariate leaf physiognomic technique based on the empirical positive correlation between mean annual temperature (MAT) and the proportions of taxa with toothed vs. taxa with entire leaf margins (woody dicots) of non-pioneer vegetation (Bailey and Sinnott, 1916). Wolfe (1979) devised this method and compiled 34 humid to mesic floras from East Asia, including the reference datasets of Wang (1961), to build a linear regression equation to predict temperature – see Eq. 6. Recently, Su et al. (2010) re-evaluated original Wolfe’s datasets and introduced a new equation (Eq. 7) from humid to mesic forests from China. Traiser et al. (2005) present regression equation (Eq. 8), which is based on European datasets containing 1835 reference sites. Sampling errors (SE1) and (SE2) were calculated by Wilf (1997) and Miller et al. (2006) – see Eq. 9 and Eq. 10. For the

assemblages from Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben, the application of LMA is strongly limited by a low abundance of leaf material in the studied floras. We therefore experimentally used elements typified by pollen and carpological remains. In such cases, the tooth and/or entire character of the leaf lamina is estimated based on the known characters of their nearest living relatives (NLRs) presented in Table 1. This indirect determination of leaf characters should influence the accuracy of the results further than estimated in Eq. 9 and 10.

Eq. 6: $\text{MAT}_{\text{LMA } 1} = 30.6 \times P + 1.41; (r^2 = 0.98),$

Eq. 7: $\text{MAT}_{\text{LMA } 2} = 27.6 \times P + 1.038; (r^2 = 0.79),$

Eq. 8: $\text{MAT}_{\text{LMA } 3} = 31.4 \times P + 0.512; (r^2 = 0.60),$

where r^2 (coefficient of determination).

Eq. 9: $\text{SE } 1_{\text{MAT}} = c \sqrt{[(P(1-P))/n]},$

where c (slope of the MAT vs. leaf margin regression, equals 30.6 here), n (total species number), P (proportion of n species with entire margin, $0 < P < 1$).

Eq. 10: $\text{SE } 2_{\text{MAT}} = \sqrt{[1 + \phi (n-1) P(1-P)] \times (P(1-P))/n},$

where $\phi = 0.052$ (dispersion factor), P ($0 < P < 1$) is the percentage of woody dicots with entire leaves; and n is the total number of woody dicots.

To compare results of LMA derived from the above presented equations (Eqs 6 to 8), a value of mean absolute deviation (MAD) was calculated as follows (Eq. 11):

400 Eq. 11: $MAD = 1/n \sum_{(i=1)}^n |x_i - \bar{x}|$,

401 where x_i (data element), \bar{x} (mean of the dataset).

402

403 **6. Palaeoenvironmental reconstruction**

404 The three palaeovegetational techniques (Phytosociological approach, IPR-vegetation
405 analysis and PCS approach) and two palaeoclimatic methods (LMA and CA) have been
406 applied on the studied plant assemblages from the Vildštejn Formation and the Tachov
407 (Cheb–Domažlice) Graben to re-evaluate and quantify the previous vegetation and climatic
408 characteristics presented by Bůžek et al. (1985) and to allow to discuss these data in the light
409 of the newly applied techniques.

410

411 **6.1 Vegetation reconstruction**

412 **6.1.1 Phytosociological approach**

413 The older part of the Vildštejn Formation, the Vonšov Member – Pluto Clay (Bůžek et al.,
414 1985, Fig. 4.1), is characterised by an assemblage indicating a mixed coniferous and broad-
415 leaved deciduous forest growing on mesic habitats (e.g., *Pinus*, *Picea*, *Larix*, *Liriodendron*,
416 *Quercus*, *Castanea*, *Taxus*, *Ilex*). However, the three latter elements documented in the
417 carpological record are usually interpreted as wetland plants (e.g., Mai and Walther, 1988).
418 This forest probably overlapped with riparian vegetation and swamps dominated by shrubs

419 and herb undergrowth (e.g., *Taxodium*, *Acer*, *Chamaecyparis*, *Ranunculus*, *Ampelopsis*,
420 *Rubus*, *Nuphar*, *Polygonum*, *Sparganium*, *Dulichium*, *Carex*, *Potentilla*, *Potamogeton*, *Najas*).

421 The studied pollen spectra of the Pluto Clay of the Vonšov Member, i.e., horizons A 1-3 of
422 the Nová Ves clay pit and the middle part of the drill cores HV 2 and HV 3 sensu Stuchlik
423 (1982), generally prove the mixed coniferous and broad-leaved deciduous forest vegetation
424 type and show a predominance of swamp and riparian elements, such as Polypodiaceae,
425 *Myrica*, *Salix*, *Alnus*, and mesophytic elements, e.g., *Betula*, *Carpinus*, *Corylus*, *Engelhardia*,
426 *Symplocos*, *Juniperus*, *Keteleeria*, *Cryptomeria*-type, *Abies* (see Table 1, Fig. 2). Bůžek et al.
427 (1985, p. 49) pointed out similar modern vegetation types from the USA and southern
428 Europe. In the USA, the area of Weymouth Pine mixed forests approaches the *Taxodium*
429 alluvial forests (with *Nyssa*, *Acer rubrum*, various deciduous oaks) and the *Chamaecyparis*
430 swamp forests. Wet areas outside forests are covered there with sedges, which include also
431 *Dulichium* (Knapp, 1965). Similarly, broad-leaved deciduous forests are known from wet soils
432 biotopes of the sub-Mediterranean zone in Europe, characterised by *Querco-Carpinetum*
433 *betuli* association, while *Pinus peuce* builds poor stands occupying higher mountain biotopes
434 over 1.500 m alt. (Horvat et al., 1974).

435 The reconstructed vegetation based on the studied plant fossils from the Tachov (Cheb–
436 Domažlice) Graben shows close affinity to those reconstructed above for the Pluto Clay.

437 The studied assemblages of the Nero Clay in the Nová Ves Member show a very similar
438 vegetation pattern corresponding to those of the Vonšov Member (see Bůžek et al., 1985,
439 Fig. 4.2). The macrofossil plant material indicates a change in floristic compositions, e.g., the
440 absence of *Quercus*, *Castanea*, *Liriodendron*, *Larix*, *Picea* contrary to new occurrences of

441 *Pinus cf. spinosa*, *Corylus*, and new aquatic elements, such as *Proserpinaca*, *Nymphaea*,
442 *Najas*, *Menyanthes*, *Juncus*, *Cyperus*, *Cladium*, *Caldesia*, while the pollen spectra show
443 almost identical taxa composition with higher abundances of Taxodioideae/Cupressaceae,
444 *Corylus*, Leguminosae, *Myrica*, and Rhamnaceae (see Table 1). A high frequency of the
445 mentioned aquatic and marsh elements corresponds to fluvial to oxbow lake or periphery of
446 basin environments within the zonal broad-leaved deciduous forest on their upland
447 periphery.

448 The vegetation reconstructions of the next stratigraphic level of the Nová Ves Member
449 (lignite beds) studied here are based on the floras of the Nová Ves pit (NV 9–10) and drill
450 core HV 4, characterised by Bůžek et al. (1985, Fig. 4.3) as mesotrophic transitional moor
451 with Cyperaceae, *Scheuchzeria*, *Menyanthes* associated with *Pinus cf. spinosa*, overlapped in
452 oligotrophic areas to vegetation dominated by Ericaceae (*Andromeda polifolia*,
453 *Chamaedaphne calyculata*, *Oxycoccus*) and in alluvial parts to forest vegetation
454 characterised by *Picea omoricoides* and *Chamaecyparis cf. pisifera*. Bůžek et al. (1985) noted
455 analogous modern vegetation in the cool temperate zones of the northern Atlantic part of
456 the USA, like the Northern broad-leaved and Weymouth Pine forest sensu Knapp, (1965, p.
457 85), and Europe; the wet rock habitats with *Picea omorika* in the Drina valley at 800-1000 m
458 alt. (Horvat et al., 1974), or the lowland peat bogs with *Chamaedaphne calyculata* in Finland
459 (Overbeck, 1975). Besides an increase in the abundance of *Pinus sylvestris* type, the pollen
460 spectra of the Nová Ves pit show a strong decrease in diversity. Abundances of herbaceous
461 and aquatic plants increase and arboreal riparian elements decrease (*Alnus*, *Salix*) indicating
462 a change especially in the azonal vegetation. The stratigraphically youngest plant fossils from

the Nová Ves clay pit (NV 14, C9, C₁₋₄, D) indicate a spreading of the coniferous forest vegetation type dominated by pines (*Pinus* cf. *halepensis*, *Pinus* cf. *sylvestris*) in the association with *Picea omoricoides*, *Abies* sp., and *Juniperus* cf. *communis*. The coniferous forest probably overlapped with riparian vegetation with *Alnus* cf. *rugosa* and *Salix* and moor and aquatic vegetation with *Menyanthes* cf. *trifoliata*, *Elatine alsinastrum*, *Andromeda polifolia*, *Artemisia*, Cyperaceae etc. (Bůžek et al., 1985, Fig. 4.4; Table 1). These vegetation types are comparable to modern vegetation known from the Taiga zone (Bůžek et al., 1985).

6.1.2 IPR-vegetation analysis results

According to the thresholds of key components for vegetation types (see the Eqs 1–5) re-established by Teodoridis et al. (2011b), possible zonal vegetation assemblages are classified (see Table 2). The number of elements per fossil flora varies from 42 to 126, and Appendix 3 shows how each element is scored for each stratigraphic level in this study. The results derived from the Vonšov Member (Pluto Clay) show a relatively high abundance of arboreal elements, i.e., BLD component (78 and 81%), BLE component (17 and 15%), and conifers (16 to 21 %), associated with slightly low values for zonal herbs varying from 32 and 33%. Such compositions of the key components correspond more or less to transitional vegetation of BLDF/MMF and BLDF vegetation types (see Teodoridis et al., 2011a, Table 2). The values of the zonal herb component exceed 30 % (the threshold for the BLDF and BLDF/MMF vegetation types according to Teodoridis et al., 2011a). Stratigraphically comparable floras from the Tachov (Cheb–Domažlice) Graben show similar results, where the values of the

484 coniferous, BLD, BLE and zonal herb components vary from 14 to 28 %, 83 to 87 %, 15 to 10
485 %, and 33 to 27 %, respectively, based on the studied macrofossil and microfossil plant
486 remnants. The characteristics of zonal elements show a close relation to the BLDF vegetation
487 type, however, in the analysis of fossil pollen one of the values for the zonal herb
488 component is higher.

489 The results of the IPR vegetation analysis calculated for the floras of the Nová Ves Member
490 (Nero Clay) show a distinct increase in the abundances of SCL + LEG component (8%) and
491 zonal herbs (35 to 39 %), but values for coniferous, BLD and BLE components are almost
492 identical with those from the older levels of the Vildštejn Formation and the Tachov (Cheb–
493 Domažlice) Graben. This specific composition can be described in two ways, as BLDF and/or
494 transitional vegetation of BLDF/MMF vegetation types.

495 The next two stratigraphic levels of the Nová Ves Member, the lignite beds and the upper
496 part, are characterised by a distinct increase in the relative abundance of the zonal herb
497 component, generally exceeding 40 % (max. 50 %, Table 2). These herbaceous elements are
498 associated with taxa of the SCL + LEG component, which are represented in relatively high
499 numbers varying from 7 to 11 %, and with BLD and BLE elements in slightly lower quantities
500 (73 to 83 % and 7 to 11 %). Abundances of the coniferous component vary from 16 to 39 %
501 of the zonal elements. The assignment of the studied floras from lignite beds of the Nová
502 Ves Member to vegetation types is equivocal and may correspond to three possible types
503 that are Xeric grasslands or steppe, transitional vegetation of BLDF/MMF and/or vegetation
504 of MMF. The studied floras from the upper part of the Nová Ves Member were excluded
505 from the analysis due to the low number of zonal angiosperms elements (Table 2).

Generally, the results of the IPR vegetation analysis indicate several important trends of vegetation changes during the Late Pliocene to Early Pleistocene period (Table 2, Fig. 7): a) increase of the DRY herb component within the general increase of zonal herbaceous elements, b) increase of the SCL + LEG component, and c) decrease of the BLE component.

6.1.3 PCS approach results

Taxa lists provided by different palaeobotanical records (pollen, leaf and carpological, see Appendix 4) show numerous discrepancies in terms of taxonomical resolution, taxa richness, and quantitative representation of the same taxon. Almost all pollen taxa have been determined at genus or family level, whilst leaf and carpological taxa provide a more detailed taxonomical identification (most of them are listed at species or genus level). The pollen record has been described as constituted by 100 taxa belonging to 61 families (ferns excluded; 35 taxa at genus level); the leaf record consists of 23 taxa attributed to 9 families (ferns excluded); within the seed and fruit record 65 taxa and 37 families have been described.

The application of the PCS approach to the fossil assemblages of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben provided separate graphical sketches for each of the three studied plant organs (pollen, leaves, fruits and seeds), as shown in Fig. 3 for the assemblages of the Nová Ves Member (Nero Clay, assemblage B). The discrepancies between these three PCSs show very well how differently the signal of ancient vegetation is recorded by different types of plant parts.

527 The pollen and leaf PCSs (Figs 3 and 5) are very similar within all the layers analysed and
528 depict a mesic forest variously dominated by conifers. The pollen records also yield some
529 information from the wetland areas, which is not recorded in the leaf flora at all but seems
530 to be predominantly represented by the fruit and seed record (Figs 3 and 4). Most probably
531 none of these different records provides an accurate picture of the palaeovegetation, but
532 the integration of information from the three sources (pollen, leaves and fruits/seeds) can
533 lead us to a more sound interpretation with respect to the qualitative reconstructions by
534 Bůžek et al. (1985). However, only for the fruit and seed record modern datasets are
535 available permitting a comparison and interpretation of PCSs in terms of palaeovegetation.
536 The four graphical sketches based on carpological data (Figs 3 and 4) show a very poor
537 arboreal cover. Most of the transect is occupied by herbaceous freshwater macrophytes and
538 hygrophilous plants, which have been found to be overrepresented in analogous modern
539 situations (Vassio, 2012). Probably the sedimentological setting of the Vildštejn Formation
540 did not allow a broad-scale representation of vegetation in the fruit and seed assemblages
541 (Appendix 4) due to the lack of concentrated carpodeposits (sensu Gee et al., 2005). The
542 absence of carpological remains of some taxa occurring in the leaf record (*Castanea*, *Acer*,
543 *Pinaceae*, *Quercus* and other *Fagaceae*) can be explained by the large dimensions of their
544 diaspores and partly by the sampling techniques (the possibility to detect a large sized seed
545 or fruit is limited in core samples). Moreover, if these plants grew in environments which
546 were not in the direct vicinity of the sedimentary basin, the rather large size of their
547 fruits/seeds would have hampered the transport to the deposition site because of the
548 probable absence of strong currents.

The Vildštejn fruit and seed-PCSs have been compared to all of the modern carpological deposit-PCSs so far obtained by analysing different types of modern vegetation and environmental situations in Northern Italy (Vassio, 2012; Vassio and Martinetto, 2012), in order to interpret the original source vegetation context. The PCS with the most similar structure to the Vildštejn PCSs was provided by a modern fruit and seed assemblage of the locality named “Orco 1” (small oxbow lake along the Orco river, San Benigno Canavese, NW Italy, 15 km apart from the Alps fringe; Fig. 6). The Orco 1 deposit-PCS (Fig. 6.3) derives from the study of a carpological assemblage formed in a small pond (20 m in diameter), which was associated to a scarcely extended wetland area, largely surrounded by mesic woodland vegetation (Figs 6.1 and 6.2). The similarity of the Orco 1 deposit-PCS to the Vildštejn PCSs (Figs 3 and 4) implies that the Vildštejn fossil assemblages could have been formed in a vegetation context similar to Orco 1. However, this is only one possibility, because it can be assumed that an “Orco 1-type” of PCS may as well occur in a different context, for example a wide wetland with far-growing mesic vegetation (no modern PCSs are presently available for this situation). In addition, several modern studies of seed and fruit assemblages in lakes and mires (e.g., Birks, 1973; Collinson, 1983; Dieffenbacher-Krall and Halteman, 2000) agreed in indicating the generalised occurrence of a very local vegetation record, with a poor to absent documentation of the regional vegetation. Thus, the PCS analysis of the Vildštejn carpofloras would suggest a detailed but very local picture of the fossil flora and vegetation.

The pollen PCSs (Figs 3 and 5) show in all cases more diversified transects with a dominant and varied woody component. It should be emphasised that these PCSs are based on the same qualitative and quantitative data which are commonly used for the interpretation of

571 palaeovegetation on the basis of pollen diagrams, and partly for this reason they show
572 several similarities to the qualitative reconstructions given by Bůžek et al. (1985).

574 **6.2 Palaeoclimatic signals**

575 **6.2.1 Coexistence Approach (CA) results**

576 Results of the Coexistence Approach (CA) analysis of macro and micro floral assemblages for
577 the studied stratigraphic levels give narrow coexistence intervals for samples from the
578 Vonšov Member (Figs 8 and 9; Tables 3 and 4). Results from the upper part of the Nová Ves
579 Member are clearly less precise due to the lower number of taxa considered especially for
580 data based on pollen. Generally, results from samples of pollen and macro flora are in very
581 good agreement and CA analysis of single pollen samples from the Pluto Clay (the Vonšov
582 Member) and the Nero Clay (the Nová Ves Member) of the drill core HV 2 and Nová Ves clay
583 pit have provided very similar numerical results (Tables 3 and 4). The fact that they show no
584 obvious temporal change documents relatively stable palaeoclimatic conditions during the
585 time of the Vonšov and the early Nová Ves Member depositional setting.

586 The quantitative results show temperature values considerably higher than present for
587 Tachov (Cheb–Domažlice) Graben, Pluto Clay (Vonšov Member) and Nero Clay (the lower
588 part of Nová Ves Member) with mean annual temperatures (MAT) of about 15 °C, winter
589 temperatures (CMMT) around 5 °C and summer temperatures (WMMT) of about 25 °C (Fig.
590 8, Tables 3 and 4). In fact, these values are very similar to the ones obtained from the Early
591 Miocene Cypris Formation (Table 4). However, samples from higher levels of Nová Ves

Member (lignite beds and upper part) provide data that are close to the present day situation with MAT of 7 °C and CMMT of about -3 °C. Only summer temperatures (WMMT) remain higher than the present day value of 16 °C (meteorological station of Cheb, Table 3, Fig. 8). Moreover, results of this parameter consist of two coexistence intervals which indicate either a transitional phase of climate change with vegetation units that are not in equilibrium or represent a mixture of climate signals. The latter could be explained either by a mixture of plant fossils originating from different contemporary vegetation zones or by a mixture of fossils from subsequent climatic settings. The latter, a mixture of different climatic signals, appears to be more likely at the beginning of the Pleistocene with its increasing climate cyclicity. Here, only high-resolution sampling and clear stratigraphic control may be able to give data of higher precision.

Similar to temperature parameters, the precipitation values show annual precipitation higher than present in the older parts of the Cheb Basin (the Tachov /Cheb–Domažlice/Graben, Pluto and Nero clays) with 800–1000 mm, and close to the present day values in the upper part of the Nová Ves Member (lignite beds and upper part) with 641–766 mm and 422–766 mm, respectively (Fig. 9, Table 3). Also precipitations of the wettest month (HMP) and of the warmest month (WMP) decrease in time, whereas the precipitation of the driest month (LMP) does not reflect significant changes. In general, precipitation data from the Cheb Basin show a development towards modern conditions.

6.2.2 Leaf Margin Analysis (LMA) results

Proxy data derived from LMA based on the studied floras/stratigraphic levels of the Vildštejn Formation and the Tachov (Cheb–Domažlice) Graben are given in Table 5. The obtained estimates for MAT show generally balanced values for the studied floras, which are independent of the used regression equations, coefficient of determination (r^2) and/or modern calibration datasets (Europe vs. SE Asia), see Eqs 6 to 8. This fact is proved by low values of MAD not exceeding 0.5 °C. With regard to the stratigraphic context, no significant trend is becoming evident during the Vildštejn Formation setting (from Pluto Clay to the mica sandy deposit of Nová Ves). Generally, the LMA data vary from 7.5 to 11.6 °C and show significantly lower values of MAT than those from CA (see Tables 3, 5 and 6). Only the MAT estimated for the upper part of the Nová Ves Member shows a comparable value to the CA data.

7. Discussion

7.1 Vegetation cover

The plant spectrum of the Vonšov Member (Pluto Clay) shows relatively high abundances of the broad-leaved deciduous (BLD) component compared to relatively low amounts of the sclerophyllous (SCL+LEG) component. The general character of the zonal vegetation type should be interpreted as an ecotonal vegetation of mixed mesophytic forest and broad-leaved deciduous forest (MMF/BLDF) and/or a BLDF vegetation type for the basal Pluto Clay and for the Tachov (Cheb–Domažlice) Graben. The results are strongly affected by low numbers of zonal woody angiosperms (i.e., 6 and 9, Table 2), which limit the reliability of the

method. However, the values for the conifer and herbaceous components are accepted in these cases, because their calculation is based on the total number of zonal elements (only results derived from the macrofossil plant material of the Tachov (Cheb–Domažlice) Graben and the Nová Ves Member had to be excluded). The relatively high abundances of zonal herbs (over 30%) make a linking to an appropriate zonal vegetation type very problematic. Kovar-Eder et al. (2008, Table 4) defined this threshold for the BLDF type as mostly $\leq 30\%$. Yet, studied living vegetation assemblages of BLDF and MMF from Japan and China show distinctly higher values of this component exceeding 30 %, e.g., assemblages of the BLDF from Shirakami Sanchi (Japan) contain 39, 47 and 53 % of zonal herbs; those from the Meili Snow Mts. (China) comprise 63 and 58 % (Teodoridis et al., 2011b, Table 7). According to the results of the IPR vegetation analyses on modern vegetation from China and Japan, Teodoridis et al. (2011b) reveal a distinct underrepresentation of zonal herbs in the fossil record, regardless of whether dealing with leaf, pollen, or fruit assemblages. This fact can be applied on the studied floras of the Vonšov Member (Pluto Clay), the Tachov (Cheb–Domažlice) Graben as well as on the floras of the Nová Ves Member (Nero Clay), see Table 2. Therefore the unequivocal results of the IPR vegetation analysis and the classifications to BLDF and BLDF/MMF types can be accepted. These predicted vegetation types for the Vonšov Member (Pluto Clay) and the Tachov (Cheb–Domažlice) Graben correspond to the syntaxonomical results previously published by Bůžek et al. (1985) as vegetation types of mesic mixed coniferous and broad-leaved deciduous forest (see chapter 6.1.1). The value of zonal conifers detected by the IPR vegetation analysis (15 to 28 %) proved the important role of the coniferous elements within the BLDF and/or transitional vegetation of BLDF/MMF.

656 Generally, the IPR-vegetation analysis results of the Nová Ves Member (Nero Clay and lignite
657 beds) show a significant increase of abundance of the SCL + LEG component in account of
658 the BLD component. Besides, the high number of dry herbaceous elements from this
659 stratigraphic level can evocate changes in the composition and structure of the vegetation
660 cover. This change can be interpreted as a transition from dense canopy vegetation of BLDF
661 or BLDF/MMF to “more open” light forests of the BLDF or MMF types in areas of zonal to
662 extrazonal uplands. The high abundance of herbaceous component exceeding 44 % indicates
663 a close relation to the vegetation type of Xeric grasslands or steppe (Kovar-Eder et al. 2008,
664 Table 4). Kovar-Eder et al. (2008) distinguished this vegetation type by three late Miocene
665 floras from Russia (Sal-Manytsh watershed, drill cores near Sinjavka and Puchljakovskij
666 farmstead). However, only the pollen flora of Puchljakovskij farmstead shows a similar
667 composition of the other key components to the floras of the Nová Ves Member
668 (Puchljakovskij farmstead: BLD 77 %, BLE 7 %, SCL+LEG 16 %, DRY HERB 24 % and MESO
669 HERB 19 %). It is evident that Xeric grasslands or steppe show higher values of DRY HERB
670 elements than our results from the Nová Ves Member, therefore this type of vegetation can
671 be excluded as a zonal model of vegetation for our studied assemblages. This fact is
672 supported also by a high proportion of arboreal pollen in the Nová Ves Member (Fig. 2), as
673 well as the above mentioned high proportion of the BLD component (73 to 83 %, Table 2,
674 Fig. 7). Similarly, the qualitative analysis carried out by Bůžek et al. (1985) considered the
675 mixed coniferous and broad-leaved deciduous forest type for the Nová Ves Member having
676 been replaced by coniferous forest (*Pinus*, *Picea*, *Juniperus*, *Abies*) during the sedimentation
677 of the upper part of the Nová Ves Member setting. Relevant azonal vegetation types show a

678 wetland to lowland swamp character dominated by shrub and herbaceous elements of
679 Ericaceae, Cyperaceae, and Poaceae that is passing into moor and aquatic environments.
680 Those are well depicted by PCS results based on carpological datasets, preferentially
681 recording such environments. In summary, the balanced values of CONIFER, BLD, BLE
682 components and the increase of zonal herbs can corroborate the existence of zonal forest
683 vegetation throughout the Vildštejn Formation setting. The distinct increase of abundances
684 of SCL + LEG and DRY HERB components from 4.5 to 10.6 % and 11 to 17 % (average values)
685 within the Vildštejn Formation should evocate a structural change from dense vegetation to
686 more open light forests rather than the transition to a steppe environment. This
687 interpretation is supported also by the palaeoclimatic data which records a temperature
688 change from clearly above to close to modern values (Fig. 8, Table 3) excluding harsh
689 climatic conditions and a consequential vegetation collapse caused by glacial events.

690 The IPR vegetation analysis has not been widely applied to Pliocene floras yet. Besides the
691 study of Kovar-Eder et al. (2006, 2008) of slightly older, i.e., latest Miocene, plant
692 assemblages from Southern Europe, only Teodoridis et al. (2009) published results from the
693 Auenheim-Sessenheim floristic complex covering a similar stratigraphic age as the floras
694 from the Cheb Basin. The carpological flora of Sessenheim "Saugbagger-Flora" and the
695 composite flora of Auenheim (based on leaves and carpology) provide abundances of the
696 key components of BLD, BLE, SCL+LEG and zonal herb components of 76.4 %, 20.3 %, 3.3 %
697 and 13.5 %, which indicate the MMF vegetation type for Sessenheim (Teodoridis et al.,
698 2009). Following the updated classification of IPR vegetation analysis sensu Teodoridis et al.
699 (2011a) such values correspond to ecotone vegetation of BLDF/MMF. The younger flora of

700 Auenheim is characterised by a predominance of BLD components (89 %) contrary to rare
701 evidence of BLE, SCL+LEG, and zonal herb (4%, 7 %, and 1.6 %), which fits to the BLDF
702 vegetation type. On the other hand, a relatively higher percentage of zonal conifers (16.39 %
703 of zonal elements) represented by mainly boreal elements, such as *Picea* and *Abies* (typical
704 of the mixed coniferous and broad-leaved deciduous forests) can be interpreted as a
705 characteristic feature of most Late Pliocene floras of Europe (Teodoridis et al., 2009) and
706 floristically corresponds to the studied floras of the Nová Ves Member (lignite beds and
707 upper part – see chapter 6.1.1, Bůžek et al., 1985).

708 The PCSs (Figs 3, 4 and 5) do not show the structure of ecotonal vegetation of mixed
709 mesophytic forest and broad-leaved deciduous forest (BLDF/MMF) because the PCSs do not
710 represent actual reconstructions of the zonal ???? palaeovegetation, in contrast to the IPR-
711 vegetation analysis. Only the pollen PCSs could better represent the original
712 palaeovegetation structure (Figs 3 and 5), but even in this case the well-known
713 overrepresentation of saccate pollen (as well as other biases) provides an inconsistent shift
714 in the appearance of the transect towards a conifer dominated woodland. The fruit and seed
715 PCSs, based on the Orco 1 modern analogue (Fig. 6), seem to reflect rather accurately the
716 wetland and aquatic plant communities. Those appear to be very similar to the modern ones
717 of central Europe, yet with the occurrence of a few exotic plants (*Decodon*, *Dulichium*,
718 *Proserpinaca*) at least in the assemblages presented on Fig. 6. Conversely, in the youngest
719 vegetation assemblage of the Nová Ves Member – upper part (Nová Ves pit NV 14 – Fig. 5D)
720 such exotic elements play no role in the vegetation, whereas the appearance of *Scheuchzeria*
721 *palustris*, in association with *Carex nigra*, points to the establishment of a cold-temperate (or

722 boreal if you prefer- it's the same) peat bog community (*Scheuchzeria-Caricetea fuscae*) in
723 the basin.

724

725 **7.2 Climate signals**

726 The climatic datasets derived by the CA analysis of the Cheb Basin floras document a general
727 decrease of temperature and precipitation parameters from the older floras of Tachov
728 (Cheb–Domažlice) Graben, Vonšov Member (Pluto Clay), and the lower part of Nová Ves
729 Member (Nero Clay) towards the younger floras from the upper part of the Nová Ves
730 Member (lignite beds and upper part). However, LMA datasets are close to the modern MAT
731 value and do not show such a cooling trend but relatively stable climatic conditions with
732 values lower than the CA results for the oldest studied floras and higher than those of CA for
733 the youngest floras (Nová Ves Member – upper part). This discrepancy in the results of both
734 methods is due to the relatively low number of entire margined taxa (23 to 33%) and could
735 be caused by the nonstandard application of the LMA technique (using non-leaf material).
736 However, the low abundances of entire elements may be also influenced by others than
737 climatic factors. Elements with dentate leaves frequently occupy riparian vegetation units
738 (wetlands in general) rather than mesophytic zonal uplands plant assemblages and therefore
739 can lead to colder estimates for riparian vegetation assemblages by physiognomic
740 techniques (LMA and Climate Leaf Analysis Multivariate Program – CLAMP) contrary to
741 Nearest Living Relative approaches (e.g., Teodoridis, 2004). In fact, this seems to be the case

742 for the lower LMA temperatures of the Vildštejn Formation and the Tachov (Cheb–
743 Domažlice) Graben compared to CA results.

744 Few Plio/Pleistocene palaeobotanical sites are reported from Central Europe which were
745 studied for climatic quantifications and could serve for comparison (see Fig. 10). Some of
746 those floras have very poor age control and are assigned to Early or Late Pliocene by floristic
747 comparison, although some lack even such information, e.g. the Frankfurt ‘Klärbeckenflora’
748 (Mädler, 1939; Krutzsch, 1988). Based on CA analysis Uhl et al. (2007) give MAT data of 14.4
749 to 15.5 °C for this flora. Floras dated to Early Pliocene (with radiometric ages from 4.55 to
750 4.2 Ma) are Gérce and Pula in Hungary. Those were analysed by Erdei et al. (2007) with
751 values for Gérce of 15.6–15.7 °C (MAT), 5.0–5.0 °C (CMMT), 24.7–24.8 °C (WMMT), 843–
752 1160 mm (MAP) and for Pula of 10.0–15.7 °C (MAT), 0.2–4.8 °C (CMMT), 24.7–24.8 °C
753 (WMMT), 619–1160 mm (MAP). Uhl et al. (2007) published MAT data derived by various
754 methods for the floras of Berga/Turingia and Willershausen. Mai and Walther (1988) as well
755 as Krutzsch (1988) correlated both floras with the Reuverian (Piacenzian, Late Pliocene).

756 Climate values for Berga/Turingia based on CA range from 13.3 to 16.6 °C (MAT), and from
757 12.5 to 16.5 °C for the locality Willershausen. All those values are very similar to the results
758 of the studied floras from the Tachov (Cheb–Domažlice) Graben, Vonšov Member and the
759 lower parts of the Nová Ves Member confirming climatic conditions during the Pliocene of
760 Central Europe, which were generally warmer and more humid than at present. Floristically,
761 the flora of the Tachov (Cheb–Domažlice) Graben seems to be comparable with the French
762 ‘Saugbagger-Flora’ whereas the floras of the Pluto and Nero Clays show closer links to the
763 Auenheim assemblage, stratigraphically assigned to Brunssumian (Zanclean, Early Pliocene)

764 and Reuverian (Piacenzian, Late Pliocene), respectively. While our datasets do not show any
 765 significant differences between the results from the oldest flora of the Tachov (Cheb–
 766 Domažlice) Graben to the slightly younger Pluto and Nero Clays, datasets from Alsace
 767 presented by Teodoridis et al. (2009) potentially suggest a slight decrease of MAT and CMMT
 768 from the stratigraphically older ‘Saugbagger-Flora’ (MAT: 15.3–15.6 °C; CMMT: 2.7 °C;
 769 WMMT: 23.6–25.1 °C; MAP: 979–1146 mm) to the Auenheim assemblage (MAT: 13.6–15.6
 770 °C; CMMT: 0.9–1.7 °C; WMMT: 23.6–24.2 °C; MAP: 979–1122 mm). Such differences might
 771 be explained by a spatial (longitudinal) differentiation of climate with warmer values further
 772 eastward and an earlier onset of Late Pliocene cooling in the western part of Central Europe.
 773 However, asynchrony of the floras seems to be more probable, especially when considering
 774 the poor age constraints of the floras on one hand and a probable forcing also of Pliocene
 775 climate and vegetation by eccentricity cycles on the other, as suggested by Popescu et al.
 776 (2006) for the Dacic Basin in Romania during 4.9 to 4.3 Ma.

777 Further quantitative climate data are available from the Lower Rhine Basin in NW Germany.
 778 For the Rotton Formation (Early Pliocene) CA analyses give values for MAT of 13.3 to 13.8 °C,
 779 for CMMT -0.1 to 4.1 °C, and for WMMT 21.1 to 26.4 °C (Hambach Rotton leaf flora –
 780 Utescher et al., 2000) and 14.1 to 14.4 °C (MAT), 1.8 to 2.7 °C (CMMT), 24.7 to 25.7 °C
 781 (Hambach Rotton carpoflora – Mosbrugger and Utescher, 1997). Floras from the Reuver
 782 Clay (carpoflora, Late Pliocene, method CA – Mosbrugger and Utescher, 1997) provide
 783 values of 13.8 to 13.9 °C (MAT) and 3.4 to 4.6 °C (CMMT) 24.7 to 24.8 °C (WWT), whereas
 784 floras from the Lower Pleistocene part of the succession give considerably lower values of
 785 10.6 to 12.4 °C (MAT), -2.8 to 1.3 °C (CMMT), and 21.7 to 23.8 °C (WMMT) (Tegelen

786 carpoflora, Tiglian C – MN17 /Gelasian/, method CA – Mosbrugger et al., 2005). Those latter
787 values correspond well to our datasets from the upper part of the Nová Ves Member (lignite
788 beds and upper part). Temperature parameters from the older floras of the Cheb Basin
789 (Tachov /Cheb–Domažlice/ Graben, Pluto and Nero Clays) are clearly warmer than those
790 from the Lower Rhine Basin, which are more similar to the data from Auenheim discussed
791 above. This might indicate a latitudinal gradient of temperatures. Nevertheless, the general
792 temporal development of temperatures with a clear cooling at the beginning of the
793 Pleistocene in the Northern Rhine Basin (Mosbrugger et al., 2005) as well as in the global
794 marine climate record (Zachos et al., 2001) seem to correlate with the results from the Cheb
795 Basin (see Table 6, Fig. 10). However, precipitation data from the Lower Rhine Basin do not
796 show any trend but stay around 1000 mm for the whole sequence. Values for the Rotton
797 Formation (Early Pliocene) are MAP 897–1151 mm, LMP 42–49 mm, HMP 109–170 mm,
798 WMP 47–53 mm (Hambach Rotton leaf flora, method CA – Utescher, et al. 2000) and MAP
799 979–1034 mm, LMP 42–43, HMP 124–139 mm, WMP 84–91 mm (Hambach Rotton
800 carpoflora, method CA – Mosbrugger and Utescher, 1997). Floras from the Reuver Clay give
801 very similar results of MAP 979–1076 mm, LMP 33–49 mm, HMP 115–127 mm, WMP 81–92
802 mm (carpoflora – Mosbrugger and Utescher, 1997). From the Lower Pleistocene level only
803 MAP values are published with 1036–1080 mm (Tegelen carpoflora, Tiglian C – MN17,
804 method CA – Mosbrugger et al., 2005).

805 Such regional differences of the temporal development in precipitation may well be due to
806 the increasing continental character of climate in the eastern parts of Central Europe in pace
807 with the Northern Hemisphere Glaciation (e.g., Sarnthein et al., 2009; Bruch et al., 2011).

808 Unfortunately, the lack of reliable age control for the studied sites as well as for parts of the
809 floras available for comparison hinders for the moment a more insightful interpretation of
810 the terrestrial climatic changes at the Pliocene/Pleistocene boundary in Central Europe.
811 Especially the increasing influence of orbital cycles on the Pleistocene climate, i.e., the
812 increased climatic forcing by obliquity and precession with the onset of the Early Pleistocene
813 (Lisiecki and Raymo, 2007), needs to be taken into account and requires higher stratigraphic
814 resolution. Such quantitative studies of Early Pleistocene pollen sequences in deed are able
815 to detect temperature and precipitation changes in phase with obliquity driven climate
816 cycles. For Southern Europe warmer and more humid than present day conditions during
817 warm phases and close to present day conditions during cold phases are documented (e.g.,
818 Klotz et al., 2006; Fauquette and Bertini, 2003), whereas in Northern Europe during cold
819 phases at least winter temperatures seem to be cooler than present (Pross et al., 2000; Pross
820 and Klotz, 2002).

821 Nevertheless, our data consistently show temperatures and precipitation higher than today
822 during the Pliocene and close to modern values in the younger levels, most probable at the
823 beginning of the Pleistocene. There is little evidence for much colder than present day
824 conditions as implied by Bůžek et al. (1985) by comparing the youngest flora with modern
825 vegetation from the Taiga zone. However, the cold end of the resulting coexistence intervals
826 may reflect such cold conditions which cannot be resolved in greater detail here. Still, as
827 shown also by data from Southern Europe (Klotz et al., 2006; Fauquette and Bertini, 2003)
828 temperatures cooler than present seem to be unlikely even during the cold phases of the
829 earliest Pleistocene climatic cycles. This implies a general overestimation of the climatic

forcing behind vegetation changes by such qualitative interpretations like the one of Bůžek et al. (1985). Or, to take it the other way, vegetation is reacting highly sensitively to environmental changes that may be only slight climatic shifts or also other factors than climate and hard to quantify.

7. Conclusions

The following bullet points conclude crucial results of this study:

- A new floristic analysis proved the original statement given by Bůžek et al. (1982, 1985) and corroborate a decreasing trend of exotic elements within the studied floras, i.e. from the older floras of the Tachov (Cheb–Domažlice) Graben related to Early Pliocene floras of central Europe, towards floras of the Pluto and Nero Clays with estimated ages of Late Pliocene (Piacenzian), to floras from the lignite beds and upper part of the Nová Ves Member characterised by a massive immigration of boreal elements.
- The results of IPR vegetation analysis indicate a vegetation transition from broad-leaved deciduous forests (Tachov /Cheb–Domažlice/ Graben) and/or ecotonal vegetation of mixed mesophytic forest / broad-leaved deciduous forests of the Pluto Clay (the Vonšov Member) and the Nero Clay (the Nová Ves Member) to “more open” light forests of the broad-leaved deciduous or mixed mesophytic types grown in areas of zonal to extrazonal uplands during the Nová Ves Member (lignite and upper beds) setting. This vegetation change is characterised by a distinct increase of abundances of SCL + LEG (11 %) and DRY HERB (16 %) components. The high percentage of herbaceous component exceeding 44 % in

851 the Nová Ves Member could indicate a close relation to the vegetation type of the Xeric
852 grasslands or steppe. However, the relatively low value of DRY HERB component and a high
853 proportion of arboreal BLD elements safely exclude this type of vegetation.

854 • The PCS approach displays the diversified information provided by three different
855 palaeobotanical datasets. Studies on modern assemblages suggest that the carpological PCSs
856 from wetland sediments, mainly deposited in low-energy environments, provide information
857 on the local vegetation structure limited to the azonal component of vegetation. Along with
858 the above-mentioned chronological vegetation trend the wetland communities show a slight
859 but significant loss of exotic elements and point to the development of vegetation contexts
860 more similar to present European ones.

861 • Palaeoclimatic signals derived from the CA analysis generally show warmer and more
862 humid conditions than present day for the Pliocene levels and comparable values to the
863 present for the youngest (early Pleistocene) level. CA results for the Vonšov Member give
864 values about 15 °C for mean annual temperature, winter temperatures around 5 °C, summer
865 temperatures about 25 °C, and an annual precipitation of more than 900 mm. CA-based
866 palaeoclimate data for the Nová Ves Member show a decreasing trend in temperatures as
867 well as in precipitation with a mean annual temperature of about 7 °C, winter temperatures
868 well below zero (-3 °C), and summer temperatures of about 16° C in the upper part of the
869 succession. This may indicate the beginning of a cooler phase at the end of the Pliocene
870 and/or beginning of Pleistocene in the Bohemian Massif area.

871 There is no evidence for colder than present-day conditions as implied by Bůžek et al. (1985)
872 by comparing the youngest flora with modern vegetation from the Taiga zone. Such a
873 qualitative interpretation seems to overestimate the climatic forcing behind the observed
874 vegetation changes.

875

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883

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1099 **Caption to tables and figures**

1100 **Fig. 1a.** Location of the studied floras of the Vildštejn Formation and Tachov (Cheb–
1101 Domažlice) Graben (modified after Bůžek et al., 1985).

1102 **Fig. 1b.** Geological sections of selected drill cores and the Nová Ves clay pit. Symbols: A.
1103 Tachov (Cheb–Domažlice) Graben, B (I.) Vonšov Member (Pluto Clay), C (II.) Nová Ves
1104 Member (Nero Clay), D. (III.) Nová Ves Member (lignite beds), and E. (IV.) the Nová Ves
1105 Member (upper part), modified after Bůžek et al. (1985). Stratigraphic data after Bucha et al
1106 (1990) and Špičíková et al. (2000); GPTS dataset modified after Lourens et al. (1996) and
1107 Petronio et al. (2011).

1108 **Fig. 2.** Simplified pollen diagrams of drill core HV 2 (a) and Nová Ves clay pit (b). The relative
1109 abundances of trees, shrubs and herbs, as well as the AP/NAP ratio are based on the sum of
1110 gymnosperm and angiosperm taxa excluding aquatic and hydrophytes to better reflect the
1111 regional vegetation. For all other taxa the total pollen sum served as the base for calculating
1112 percentages. For details and full taxa list see Appendix 1.

1113 **Fig. 3.** Plant Community Scenario diagrams (PCSs) provided by carpological, leaf and pollen
1114 records from the Vildštejn Formation, stratigraphic level/horizon B (Vonšov Member – Pluto
1115 Clay). Notice that the PCSs do not represent actual reconstructions of the
1116 palaeoenvironment and palaeovegetation, rather they are a graphical representation of
1117 quantitative palaeobotanical data. Each typology of plant symbol is referred to a group of
1118 taxa that shares habitus, size and ecological features (Martinetto and Vassio, 2010; Vassio,
1119 2012, Vassio and Martinetto, 2012). Fifty plant symbols and twenty-five taxa names, among

1120 the most frequent floristic elements, have been reported into the diagram by taking into
1121 account their ecological requirement, expressed by the belts in different colour. The breadth
1122 of each belt is proportional to the frequency of plants classified as mesophytic, hygrophilous
1123 or aquatic in the fossil assemblage; also the proportion of different plant symbols reflects
1124 the frequencies of the taxa belonging to each 'growth form' group within the fossil
1125 assemblages (e.g., broad-leaved deciduous shrub short/medium/tall, broad-leaved
1126 deciduous tree short/medium/tall, evergreen conifer tree Pinaceae, aquatic submergent
1127 herb short/medium/tall etc.).

1128 **Fig. 4.** Plant Community Scenario diagrams provided by carpological records from the
1129 Vildštejn Formation and Tachov (Cheb–Domažlice) Graben. Stratigraphical levels/horizons: A
1130 (Tachov /Cheb–Domažlice/ Graben), C (Nová Ves Member – Nero Clay), D (Nová Ves
1131 Member – lignite beds). For B (Vonšov Member – Pluto Clay), see Fig. 3

1132 **Fig. 5.** Plant Community Scenario diagrams provided by pollen records from the Vildštejn
1133 Formation. Stratigraphic levels/horizons: C (Nová Ves Member – Nero Clay), D (Nová Ves
1134 Member – lignite beds), E (Nová Ves Member – upper part). For B (Vonšov Member – Pluto
1135 Clay), see Fig. 3.

1136 **Fig. 6.** Plant Community Scenario diagrams (PCSs) provided by carpological records from the
1137 modern locality Orco 1 (San Benigno Canavese, NW Italy). – 1. vegetation-PCS obtained from
1138 the standing vegetation survey of the area (diameter length ca. 100 m) ahead of the small
1139 pond from where a fruit-bearing sediment sample was analysed. 2. vegetation-PCS obtained
1140 from the standing vegetation survey of a small wetland crossed by a brook, extended few

1141 tens of meters ahead of the small pond. 3. deposit-PCS obtained from a modern fruit and
 1142 seed assemblage buried in the silty sediments of the pond. The three PCSs clearly show that
 1143 this fruit and seed assemblage provides a very local record of the vegetation: the aspect of
 1144 the transect is similar to the wetland vegetation close to the pond, and the signal of the
 1145 mesophytic woodland which grows just 20 m apart of the pond is not well recorded by the
 1146 carpological assemblage.

1147 **Fig. 7.** General vegetation changes and trends based on the IPR vegetation results of the
 1148 studied floras from the Vildštejn Formation and Tachov (Cheb–Domažlice) Graben during the
 1149 Late Pliocene to Early Pleistocene period. Symbols: % CONIFER (percentages of zonal and
 1150 extrazonal conifers), % BLD (percentages of broad-leaved deciduous woody angiosperms), %
 1151 BLE (percentages of broad-leaved evergreen woody angiosperms), % SCL+LEG (percentages
 1152 of sclerophyllous woody and legume-like woody angiosperms), % DRY HERB (percentages of
 1153 open woodland and grassland elements), % MESO HERB (percentages of mesophytic forest
 1154 undergrowth elements), and % zonal herb (percentages of zonal herbaceous elements, = %
 1155 DRY HERB + % MESO HERB). The parameters are calculated based on the equations 1–5. A
 1156 (Tachov/Cheb–Domažlice/ Graben), B (Vonšov Member – Pluto Clay), C (Nová Ves Member –
 1157 Nero Clay), D (Nová Ves Member – lignite beds).

1158 **Fig. 8.** Palaeoclimatic quantification of temperature parameters based on the Coexistence
 1159 Approach, for MAT (mean annual temperature), CMMT (mean temperature of the coldest
 1160 month) and WMMT (mean temperature of the warmest month) derived from the
 1161 Coexistence Approach (CA). Symbols: A (Tachov/Cheb–Domažlice/ Graben), B (Vonšov
 1162 Member – Pluto Clay), C (Nová Ves Member – Nero Clay), D (Nová Ves Member – lignite

beds), E (Nová Ves Member – upper part), green square (based on macrofossil plant remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macro- and microfossil plant remnants), solid vertical lines (present day climatic data from the meteorological station of Cheb). For data source see Table 3.

Fig. 9 Palaeoclimatic quantification of temperature parameters based on the Coexistence Approach, for MAP (mean annual precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest month) and WMP (precipitation of the warmest month) derived from the Coexistence Approach (CA). Symbols: A (Tachov/Cheb–Domažlice/ Graben), B (Vonšov Member – Pluto Clay), C (Nová Ves Member – Nero Clay), D (Nová Ves Member – lignite beds), E (Nová Ves Member – upper part), green square (based on macrofossil plant remnants), yellow circle (based on microfossil plant remnants), red rhomb (based on macro- and microfossil plant remnants), solid vertical lines (present day climatic datasets from the meteorological station of Cheb). For data source see Table 3.

Fig. 10. Comparison of palaeoclimatic proxy data based on the Coexistence Approach (CA) from the studied floras of the Vildštejn Formation, Tachov (Cheb–Domažlice) Graben and selected Pliocene and Pleistocene floras of Europe . – Symbols: 1. Tachov (Cheb–Domažlice) Graben, 2. Frankfurt ‘Klärbeckenflora’ (Germany), 3. Gérce (Hungary), 4. Pula (Hungary), 5. Berga (Germany), 6. Willershausen (Germany), 7. Sessenheim (France), 8. Hambach Rotton (Germany) – leaf, 9. Hambach Rotton (Germany) – carpology, 10. Vonšov Beds (Pluto Clay), 11. Nová Ves Beds (Nero Clay), 12. Auenheim (France), 13. Reuver Clay (Germany), 14. Nová Ves Beds (lignite beds), 15. Nová Ves Beds (upper beds), and 16. Tegelen (the Netherlands).

1184

1185 **Table 1.** Summary of the floristic compositions of the studied floras of the Vildštejn
1186 Formation and Tachov (Cheb–Domažlice) Graben including suggested Nearest Living
1187 Relatives. Symbols: C (cone), F (fruit), L (leaf), P (pollen), S (seed), Sp (spore) and W (wood)

1188 **Table 2.** Results of the IPR vegetation analysis from the studied floras of the Vildštejn
1189 Formation and Tachov (Cheb–Domažlice) Graben. Symbols: L (leaf flora), F (fruit and seed
1190 flora), P (pollen flora). Percentages of the BLD (broad-leaved deciduous woody
1191 angiosperms), BLE (broad-leaved evergreen woody angiosperms), SCL+LEG (sclerophyllous
1192 woody and legume-like woody angiosperms), DRY HERB (open woodland and grassland
1193 elements), MESO HERB (mesophytic forest undergrowth elements) components were
1194 calculated following the equations 1 to 4 .

1195 **Table 3.** Results of the palaeoclimatic quantification based on the Coexistence Approach for
1196 the studied floras from the Vildštejn Formation and Tachov (Cheb–Domažlice) Graben
1197 including the limiting taxa of the coexistence intervals. Symbols: L (leaf flora), F (fruit and
1198 seed flora), P (pollen flora), MAT (mean annual temperature), CMMT (mean temperature of
1199 the coldest month), WMMT (mean temperature of the warmest month), MAP (mean annual
1200 precipitation), HMP (precipitation of the driest month), LMP (precipitation of the driest
1201 month) and WMP (precipitation of the warmest month). The source of climatic parameters
1202 from the meteorological station of Cheb is derived from the website of the Czech
1203 Hydrometeorological Institute (<http://www.chmi.cz>).

1204 **Table 4.** Results of the palaeoclimatic quantification based on the Coexistence Approach for
1205 the studied fossiliferous horizons of drill core HV 2 and levels of Nová Ves clay pit (the
1206 Vildštejn Formation) based on micro (pollen) plant remains. Symbols: MAT (mean annual
1207 temperature), CMMT (mean temperature of the coldest month), WMMT (mean temperature
1208 of the warmest month), MAP (mean annual precipitation), HMP (highest monthly
1209 precipitation) LMP (lowest monthly precipitation) and (WMP) precipitation of the warmest
1210 month.

1211 **Table 5.** Palaeoclimate proxy data of MAT (mean annual temperature) derived from Leaf
1212 Margin Analysis were calculated following the equations 5 to 7 as well as values of sampling
1213 errors (Eqs 8 to 9) and mean absolute deviation (Eq. 10). Symbols: n (total species number),
1214 P (proportion of n species with entire margin, $0 < P < 1$).

1215 **Appendix 1.** Raw data pollen counts of drill core HV 2 and Nová Ves clay pit (Vildštejn
1216 Formation).

1217 **Appendix 2.** List of acronyms, growth forms and plant symbols used within Plant Community
1218 Scenario (PCS). The symbol size for herbaceous plants are twice as large as they are drawn in
1219 the PCSs in order to make their visualization easier (modified after Vassio and Martinetto,
1220 2012).

1221 **Appendix 3.** Plant taxa occurring in the studied floras from the Vildštejn Formation and
1222 Tachov (Cheb–Domažlice) Graben and their scoring according to the IPR-vegetation analysis.

1223 **Appendix 4.** Quantitative and qualitative datasets of Plant Community Scenario diagrams
1224 (PCSs) referred to floristic lists obtained by leaf, pollen and carpological record analyses
1225 within Vildštejn Formation (Table 1) and by actuopalaeobotanical analysis on carpological
1226 assemblages in modern sediments from NW Italy, Orco 1 (Fig. 6) – details in Vassio (2012).
1227 The datasets comprise also calculation useful in PCS construction on the basis of absolute
1228 quantitative data (column A) transformed into percentages (column X (%)). The percent
1229 values are summed up by grouping taxa a) belonging to the same ecological zone in order to
1230 obtain the X, M, HY and A zone extension within the PCS transects (X – xerophytic, M –
1231 mesophytic, HY – hygrophilous, A – aquatic); b) with the same growth form in order to
1232 define how many plant symbols of each type to be drawn in the PCS (see Appendix 2,
1233 modified after Vassio, 2012 and Vassio and Martinetto, 2012). ‘Plant organs’ column
1234 abbreviations: S (seed), F (fruit), Sp (spore), mC (male cone), Cs (cone scale), L (leaf), P
1235 (pollen).